Use of Electronic Tag Data and Associated Analytical Tools to Identify and Predict Habitat Utilization of Marine Predators

Daniel P. Costa
University of California, Santa Cruz
100 Shaffer Rd.
Santa Cruz, CA 95060
phone: (831) 459-2786 fax: (831) 459-3383 email: costa@biology.ucsc.edu

Award Number: N00014-08-1-1195

Barbara Block
Stanford University
Hopkins Marine Station
120 Ocean View Blvd
Pacific Grove, CA 93950-3024
phone: (831) 655-6236 fax: (831) 375-0793 email: bblock@stanford.edu

Award Number: N00014-08-1-1196

LONG-TERM GOALS

Key to assessing the risk of naval activities (such as sound exposure) on marine animals is an understanding of where animals occur and what factors motivate these movements. The rapid advancement of electronic tracking and remote sensing technologies has enabled researchers to link pelagic predator movements and oceanic processes. This information is critical for understanding distribution and residence time of vertebrates within an ocean area and for managing interactions with anthropogenic activities. Marine predators interact with a dynamic ocean that change on time scales ranging from minutes to millennia. Knowledge of these movement interactions is incomplete but critical to understanding dynamic distributions, managing anthropogenic disturbance, and predicting responses to climate change. This proposal utilizes the largest database of existing marine vertebrate tracking and behavior data to build upon the significant advances in tag technology, data analyses and management accomplished under the Tagging of Pacific Predators (TOPP) program. This will be accomplished by establishing a behavioral baseline to assess the potential costs of displacement in terms of reduced foraging success. The project also involves a synthesis of electronic tracking and remote sensing data, focusing on a cross-taxa examination of marine predator distribution and movement patterns to identify hotspots, foraging patterns and movement corridors in the California Current.

OBJECTIVES

1) Identify and map focal feeding, breeding, and migration routes.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
2012	**N/A**	**-**

4. TITLE AND SUBTITLE	
Use of Electronic Tag Data and Associated Analytical Tools to Identify and Predict Habitat Utilization of Marine Predators	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **University of California, Santa Cruz 100 Shaffer Rd. Santa Cruz, CA 95060**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**SAR**	**6**	

2) Model spatio-temporal oceanographic habitat utilization and predict regions of animal occupancy and use based on oceanographic features.

3) Utilize this model framework to assess the impact of displacement from primary feeding areas due to disturbances (such as acoustic disturbance).

APPROACH

There are two distinct components to this effort, each of which addresses a project objective. First, we will use existing TOPP tracking data to generate overall utilization distributions as well as single species distributions and further categorize track segments by behavioral state using a combination of state spaced models and the fractal landscape method to determine regions of area restricted search (ARS) (Jonsen et al. 2003; Jonsen et al. 2006; Tremblay et al. 2007). Next, we will model the links between oceanographic parameters and animal movement patterns. The output from these models will be used to develop predictive models of marine vertebrate distribution based on oceanographic parameters.

WORK COMPLETED

Deployments of 4,306 electronic tags yielded 1,791 individual animal tracks from 23 species, totaling 265,386 animal tracking days (Figure 1). Technologies had different location precisions, including: Argos satellite tags (n=1,183), archiving and satellite transmitting tags (n=1,008), and archival geolocation tags (n=2,115) the latter two of which provide estimates of position based on sunlight, time, and sea surface temperatures (SST). These different positions first required the estimates of the precision of each method, coupled with incorporation of all the data into a state based model. Once this was accomplished all tracking data were reduced to a single position each day for each individual animal. These data were then used in the final analysis.

RESULTS

The tracking data reveal that the California Current Large Marine Ecosystem (CCLME; Supplementary Figure 1) is an important habitat (Figures 2-4) for tunas (Pacific bluefin, *Thunnus orientalis*; yellowfin, *T. albacares*), sharks (shortfin mako, *Isurus oxyrinchus*; white, *Charcharodon carcharias*; salmon, *Lamna ditropis*; blue, *Prionace glaucus*; common thresher, *Alopias vulpinus*), cetaceans (blue whales, *Balaenoptera musculus*), pinnipeds (Northern elephant seals, *Mirounga angustirostris*; California sea lions, *Zalophus californianus*), seabirds (Laysan albatross, *Phoebastria immutabilis*; black-footed albatross, *P. nigripes*; sooty shearwaters, *Puffinus griseus*), and turtles (leatherback turtle, *Dermochelys coriacea*; loggerhead turtle, *Caretta caretta*). Annual migratory periodicity was evident in the movements of many tagged animals that showed fidelity to the cool, nutrient rich waters of the CCLME (Figure 2-3). Extended residency within the CCLME was revealed by examining tracks that spanned multiple seasons using a switching state-space model (Figure 3). Numerous species exhibited a strong attraction to the CCLME and undertook long migrations (> 2,000 km) from the western, central, or south Pacific basin (leatherback sea turtles, black-footed albatrosses, sooty shearwaters, bluefin tuna, and salmon sharks; Figure 2b). Species exhibited a seasonally recurring north-south migration (bluefin and yellowfin tunas, mako, white, and salmon sharks, blue whales, male elephant seals and leatherback sea turtles; Figure 3g-l) in the North Pacific and within the CCLME. Other taxa undertook movements between nearshore and offshore waters, with a residency period within the CCLME or Gulf of Alaska, followed by an offshore migration that ranged into the

North Pacific Transition Zone (female elephant seals, salmon sharks, Laysan albatrosses), the Subtropical Convergence Zone (blue and mako sharks, leatherback turtles), or the eastern Pacific and Hawaiian Islands (white sharks, albacore tuna, and black-footed albatrosses). The mechanisms and cues underlying fidelity to seasonally-modulated migration pathways are not entirely known, but may represent a capacity to discriminate among areas of seasonal significance for foraging, or reproduction.

The CCLME is a highly retentive area for many species tagged there, and an attractive area for animals undergoing long migrations from the western and central North Pacific and Gulf of Alaska (Figures 2; 4a,b). Pacific bluefin and yellowfin tunas spent significantly more time in the CCLME than expected based on null model simulations. Several species - tunas; lamnid sharks; leatherback turtles; and blue whales had substantial residency periods within, or were return migrants to the CCLME based on behavioral inferences from a switching state-space model[16] (Figure 4c). Additionally, all species tagged outside the CCLME spent significantly more time on average in the CCLME than expected based on null model simulations. Representatives from several guilds exhibited cross-basin migrations (> 2,000 km) into the CCLME from the western (leatherback turtle, bluefin tuna), central (black-footed albatross, salmon shark), and south Pacific basins (sooty shearwaters; Figure 2b). The retention with and attraction to the CCLME is consistent with the high productivity of this region that supports large biomasses of krill, sardines, anchovies, salmon, groundfish, and squid providing a predictable forage base for top predators. The NPTZ is another important region, serving as an east-west migration corridor (Figure 4a) and foraging region for elephant seals, salmon and blue sharks (Figure 4c), Laysan and black-footed albatrosses, and bluefin tuna (Figure 1). This is a complex region encompassing an abrupt north-to-south transition between subarctic and subtropical water masses with dynamic frontal regions.

The second component of this effort was to identify the oceanographic parameters responsible for the distribution of these predators. To investigate which aspects of the biophysical environment putatively attract these predators, we explored both presence/absence and relative habitat use with generalized additive mixed models. We examined the collective response of 16 marine predator species to environmental covariates. In the binary presence/absence model, predator incidence showed a strong positive relationship with SST, across a broad temperature range and peaking near 15˚C. Tagged animals occupied a small portion of cool, nutrient-rich water in coastal regions and northern latitudes compared to the broadly available warm oligotrophic waters in lower latitudes. The strong positive relationship between relative density and Chl-*a* suggests the suite of tagged species are preferentially occupying regions of high productivity. The observed patterns of predator distribution in this study may be indicative by trade-offs between thermal tolerances, either directly by the predators or indirectly on lower trophic levels, and access to areas of higher productivity.

To examine how closely related taxa partition marine resources, we compared thermal preferences from *in-situ*, tag-based SST measurements for sympatrically occurring species within three guilds (albatrosses, tunas, sharks). Differences in habitat utilization evident among congeneric species illustrate how recently divergent species partition the oceanic environment (Figure 5). During the June to November post-breeding phase, black-footed albatrosses were associated with a broader and warmer range of SST primarily in the eastern Pacific, whereas Laysan albatrosses were associated with a narrower and colder range of SST in the western and central North Pacific (Figure 5a). Bluefin tuna ranged farther north in the colder waters of the CCLME, whereas yellowfin occupied warmer waters in the southern CCLME (Figure 5b). These differences are consistent with physiological specializations in bluefin tuna cardiac performance. The lamnid sharks had a more complex separation of habitats. Salmon sharks, with their cold tolerant cardiac physiology, occupied the cooler, subarctic waters in the

North Pacific. Most salmon sharks, but not all, migrated seasonally into the warmer NPTZ and CCLME waters (Figure 5c). White sharks overlapped with salmon sharks in the nearshore CCLME, but also migrated into warmer, offshore waters of the Subtropical Gyre[12] and the Hawaiian Islands (Figure 5c). Shortfin makos were distributed throughout the CCLME and into the Subtropical Gyre, but occupied a thermal range intermediate to the two modes of the white shark range (Figure 5c).

IMPACT/APPLICATIONS

Critical to determining the impact of exposure to naval operations on marine animals is relating the intensity and duration of an exposure to the time animals spend in proximity to the source, and the biological function of that time. The proposed predictive models of critical marine animal habitat utilization are the essential behavioral components to determine whether and where naval operations might impact marine mammals and other marine vertebrates.

RELATED PROJECTS

JIP: Relating Behavior and Life Functions to Populations Level Effects in Marine Mammals: An empirical and modeling effort to develop the PCAD model. Contract JIP 22 07-23

PUBLICATIONS

Breed, G. A., D. P. Costa, I. D. Jonsen, P. W. Robinson, and J. Mills-Flemming. 2012. State-space methods for more completely capturing behavioral dynamics from animal tracks. Ecological Modelling **235–236**:49-58.

Caro, T., T. Stankowich, S. L. Mesnick, D. P. Costa, and K. Beeman. 2012. Pelage coloration in pinnipeds: functional considerations. Behavioral Ecology **23**:765-774.

Champagne, C. D., D. S. Houser, D. P. Costa, and D. E. Crocker. 2012. The Effects of Handling and Anesthetic Agents on the Stress Response and Carbohydrate Metabolism in Northern Elephant Seals. PLoS ONE **7**.

Costa, D. P. 2012. A Bioenergetics Approach to Developing the PCAD Model. Pages pages 423-426. in *in* A. N. Popper and A. Hawkins, editors. The Effects of Noise on Aquatic Life. Advances in Experimental Medicine and Biology Springer Science+Business Media.

Costa, D. P., G. Breed, and P. W. Robinson. 2012. New Insights in Pelagic Migrations: Implications for Ecology and Conservation. Annual Reviews Ecology Evolution and Systematics. Annual Review of Ecological Systematics **in press**.

Costa, D. P. and S. A. Shaffer. 2012. Seabirds and Marine Mammals. Pages 225-233 *in* R. M. Sibly, J. H. Brown, and A. K. Brown, editors. Metabolic Ecology: A Scaling Approach. John Wiley & Sons, Ltd.

Crocker, D. E., R. M. Ortiz, D. S. Houser, P. M. Webb, and D. P. Costa. 2012. Hormone and metabolite changes associated with extended breeding fasts in male northern elephant seals (Mirounga angustirostris). Comparative Biochemistry and Physiology a-Molecular & Integrative Physiology **161**:388-394.

Davidson, A. D., A. G. Boyer, H. Kim, S. Pompa-Mansilla, M. J. Hamilton, D. P. Costa, G. Ceballos, and J. H. Brown. 2012. Drivers and hotspots of extinction risk in marine mammals. Proceedings of the National Academy of Sciences **109**:3395-3400.

Evans, A. R., D. Jones, A. G. Boyer, J. H. Brown, D. P. Costa, S. K. M. Ernest, E. M. G. Fitzgerald, M. Fortelius, J. L. Gittleman, M. J. Hamilton, L. E. Harding, K. Lintulaakso, S. K. Lyons, J. G. Okie, J. J. Saarinen, R. M. Sibly, F. A. Smith, P. R. Stephens, J. M. Theodor, and M. D. Uhen. 2012. The maximum rate of mammal evolution. Proceedings of the National Academy of Sciences **109**:4187-4190.

Hazen, E. L., S. Jorgensen, R. R. Rykaczewski, S. J. Bograd, D. G. Foley, I. D. Jonsen, S. A. Shaffer, J. P. Dunne, D. P. Costa, L. B. Crowder, and B. A. Block. 2012. Predicted habitat shifts of Pacific top predators in a changing climate. Nature Clim. Change **advance online publication**.

Hooker, S. K., A. Fahlman, M. J. Moore, N. A. de Soto, Y. B. de Quiros, A. O. Brubakk, D. P. Costa, A. M. Costidis, S. Dennison, K. J. Falke, A. Fernandez, M. Ferrigno, J. R. Fitz-Clarke, M. M. Garner, D. S. Houser, P. D. Jepson, D. R. Ketten, P. H. Kvadsheim, P. T. Madsen, N. W. Pollock, D. S. Rotstein, T. K. Rowles, S. E. Simmons, W. Van Bonn, P. K. Weathersby, M. J. Weise, T. M. Williams, and P. L. Tyack. 2012. Deadly diving? Physiological and behavioural management of decompression stress in diving mammals. Proceedings of the Royal Society B-Biological Sciences **279**:1041-1050.

Jeglinski, J. W. E., C. Werner, P. W. Robinson, D. P. Costa, and F. Trillmich. 2012a. Age, body mass and environmental variation shape the foraging ontogeny of Galapagos sea lions. Marine Ecology Progress Series **453**:279-296.

Jeglinski, J. W. E., C. Werner, P. W. Robinson, D. P. Costa, and F. Trillmich. 2012b. Age, body mass and environmental variation shape the foraging ontogeny of Galapagos sea lions. Marine Ecology-Progress Series **453**:279-296.

Maxwell, S. M., J. J. Frank, G. A. Breed, P. W. Robinson, S. E. Simmons, D. E. Crocker, J. P. Gallo-Reynoso, and D. P. Costa. 2012. Benthic foraging on seamounts: A specialized foraging behavior in a deep-diving pinniped. Marine Mammal Science **28**:E333-E344.

Robinson, P. W., D. P. Costa, D. E. Crocker, J. P. Gallo-Reynoso, C. D. Champagne, M. A. Fowler, C. Goetsch, K. T. Goetz, J. L. Hassrick, L. A. Huckstadt, C. E. Kuhn, J. L. Maresh, S. M. Maxwell, B. I. McDonald, S. H. Peterson, S. E. Simmons, N. M. Teutschel, S. Villegas-Amtmann, and K. Yoda. 2012. Foraging Behavior and Success of a Mesopelagic Predator in the Northeast Pacific Ocean: Insights from a Data-Rich Species, the Northern Elephant Seal. PLoS ONE **7**.

Schwarz, L. K., M. A. Hindell, C. R. McMahon, and D. P. Costa. 2012. The implications of assuming independent tag loss in southern elephant seals. Ecosphere **3**:art81.

Villegas-Amtmann, S., S. Atkinson, A. Paras-Garcia, and D. P. Costa. 2012. Seasonal variation in blood and muscle oxygen stores attributed to diving behavior, environmental temperature and pregnancy in a marine predator, the California sea lion. Comparative Biochemistry and Physiology a-Molecular & Integrative Physiology **162**:413-420.

Winship, A. J., S. J. Jorgensen, S. A. Shaffer, I. D. Jonsen, P. W. Robinson, D. P. Costa, and B. A. Block. 2012. State-space framework for estimating measurement error from double-tagging telemetry experiments. Methods in Ecology and Evolution **3**:291-302.

HONORS/AWARDS/PRIZES

Barbara E. Block received the Rolex Award